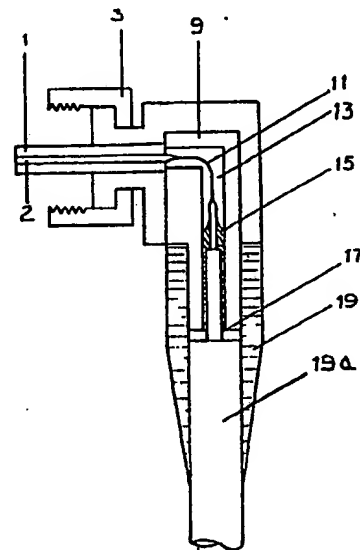


## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/US91/04322 <b>(22) International Filing Date:</b> 17 June 1991 (17.06.91) <b>(30) Priority data:</b> 539,010 15 June 1990 (15.06.90) US <b>(60) Parent Application or Grant</b> <b>(63) Related by Continuation</b> US 539,010 (CIP) Filed on 15 June 1990 (15.06.90) <b>(71) Applicant (for all designated States except US):</b> ASTER CORPORATION [US/US]; 113 Cedar Street, Milford, MA 01757 (US).	<b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only) :</b> STOWE, David, W. [US/US]; 4 Woodfall Road, Medfield, MA 02052 (US). FITZGERALD, Paul, W. [US/US]; 7 Newell Avenue, Southbridge, MA 01559 (US). GILLHAM, Frederick, J. [US/US]; 16 High Street, Westboro, MA 01581 (US).  <b>(74) Agent:</b> WILLIAMS, John, N.; Fish & Richardson, 225 Franklin Street, Boston, MA 02110 (US).  <b>(81) Designated States:</b> AT, AT (European patent), AU, BB, BE (European patent), BF (OAPI patent), BG, BJ (OAPI patent), BR, CA, CF (OAPI patent), CG (OAPI patent), CH, CH (European patent), CI (OAPI patent), CM (OAPI patent), DE, DE (European patent), DK, DK (European patent), ES, ES (European patent), FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), GN (OAPI patent), GR (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MN, MR (OAPI patent), MW, NL, NL (European patent), NO, PL, RO, SD, SE, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent), US.  <b>Published</b> <i>With international search report.</i>	
<b>(54) Title:</b> MINIATURE FIBEROPTIC BEND DEVICE AND METHOD  <b>(57) Abstract</b>  <p>Bends in optical fibers (14) can be miniaturized by reducing the diameter of a section (18) of the fiber in the region where bending (20) is desired. In one aspect of the invention radii of curvature less than 100 microns and very low optical power loss are achieved. A fiber with greatly reduced diameter (Fig. 1d, Section b-b) may also be twisted about its longitudinal axis to a greater degree than a comparable length of larger diameter fiber. In another aspect of the invention, reducing the cross-sectional area of fiber is not required. Bent sections of the fiber are thermally annealed forming stress free bends of minimum bend radius for long term applications. Any optical fiber can be processed by redrawing and/or chemical means to allow such bending or twisting. Bend or twist tolerant regions and annealed bends may be packaged separately or built integrally into a wide range of fiber optic components, sensors, networks, or systems with significant space savings, added performance features and mechanical flexibility.</p>		



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## MINIATURE FIBEROPTIC BEND DEVICE AND METHOD

### Field of the Invention

The invention relates to a family of new fiber  
5 routing components. The invention also relates to  
providing bends in optical fibers with no appreciable  
loss of optical power and without fracturing the fiber or  
affecting its longevity. The invention also relates to  
packaging electro-optical and fiberoptic components in  
10 greatly reduced package volumes. The invention further  
relates to twisting optical fibers without incurring  
breakage or loss of optical power.

### Background of the Invention

Panel connections of glass fiberoptic cables are  
15 often cumbersome and inefficient. An example is a patch  
panel for a communications network in which a great  
number of side-by-side fiber cables are connected endwise  
to the face of the panel. The cables extend outwardly in  
a group and bend only gradually from the connection to  
20 avoid mechanical failure of the glass fibers and signal  
loss. Routing of fiber cables in restricted spaces, as  
in an automobiles, presents similar problems.

Fiberoptic device packages are often large and  
cumbersome due to large radius bends required in glass  
25 fibers within the packages.

### Summary of the Invention

According to one aspect of the invention we have  
realized that small routing devices that reorient the  
fiber path from one axis to another over a short distance  
30 are both practical to realize and can contribute  
significantly to routing of optical fibers.

In achieving many such configurations the bent  
fiber portion is provided in a special treated state that  
reduces likelihood of mechanical failure over time.

Depending upon the application and the particular treatment employed, bend loss of say 10 percent may be tolerated or bend loss can be reduced to a minimal amount. Treatment includes reduction in diameter and/or  
5 annealing heat treatment, and/or provision, effectively, of air cladding in the region of the bend.

According to one aspect of the invention a routing device is provided for changing the direction of a fiberoptic path from a first axis to a second axis. The  
10 routing device comprises a short length of low-loss optical fiber having first and second directed portions aligned respectively with the first and second axes and a mid-fiber portion integral with and extending through an arc of radius of the order of two centimeters or less  
15 between the first and second directed fiber portions. The mid-portion of fiber is in a treated state that reduces likelihood of mechanical failure over time without introducing substantial optical loss, e.g., the diameter is reduced relative to the main portion of the  
20 fiber, or the fiber is bent and annealed to reduce bending stresses. This treated section of fiber is typically housed in an outer member that fixes the first and second directed fiber portions relative to one another in a predetermined, desired angular relationship.  
25 The outer member also serves to protect the first and second directed portions and the mid-portion from the environment.

According to a more particular aspect of the invention, a selected length of optical fiber, in a  
30 region where the exterior of the fiber is exposed to an external environment having an index of refraction substantially lower than that of the solid clad layer, is reduced in diameter in a manner to cause the fiber to conduct light by internal reflection attributable at  
35 least in part to the difference in index of refraction at

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the interface between the exterior of the fiber and the external environment. By this means light energy can be transmitted through the region with substantially lower bend-loss than a similarly bent section of the main length of the fiber, and it is in this region that the fiber is oriented differently, e.g. bent and/or twisted relative to an adjacent portion of the fiber, without causing substantial light loss attributable to the orientation. In both single mode and multimode fibers, the optical mechanism which allows a very significant reduction in bend radius relates to the change of waveguide structure accompanying diameter reduction. Optical fibers typically have a core with index of refraction  $N_1$  somewhat greater than the index of the surrounding cladding material  $N_2$ . It is customary to characterize the relationship between core and cladding indices by a percentage difference  $\Delta$  (delta) defined by equation 1 below. The term, delta, is sometimes called the profile parameter.

$$\Delta = (N_1^2 - N_2^2) / 2N_1^2 \quad (1)$$

Delta usually ranges from .001 to .030 with most fiber materials. This means that  $N_1$  and  $N_2$  are very nearly the same and often in the range of 1.5. Such fibers are referred to as weakly guiding fibers because of the low value of index difference. The greater the value of delta, the less susceptible a fiber to bending losses.

When the diameter of the fiber is reduced, for example by heating and redrawing the heated region, the cladding and core diameters are both reduced. It is found that eventually the outer diameter of the reduced fiber becomes so small that the original cladding material is no longer effective as a cladding. The fiber becomes essentially clad by the surrounding medium. In

the event that the surrounding medium is air, the value of  $N_2$  decreases to 1.0. For typical cores having  $N_1$  in the range of 1.5, this results in an increase in delta of about 100 fold. Because of this dramatic increase in  
5 delta, the reduced diameter fiber is able to guide light around much smaller bends than the original fiber without loss of light.

Because this aspect of the invention enables the achievement of miniature bends relative to those  
10 heretofore achieved, this aspect of the invention is sometimes referred to as the "miniature bend invention", but the concepts and contributions go far beyond that important achievement.

In another aspect of the invention conventional  
15 fibers are bent into a predetermined shape and permanently annealed in that shape to achieve a routing device. A fiberoptic path is formed within a selected region of unaltered optical fiber wherein the selected region is bent to a predetermined radius of curvature and  
20 subsequently heated to a suitable annealing temperature. The heating is controlled in a manner to relax mechanical bending stress in the selected region without increasing the optical power loss attendant to the predetermined bend. The bend may extend through an angular range  
25 substantially greater than zero angular degrees and may exceed multiples of 360 angular degrees, e.g., the fiber may be coiled. The bend has optical power loss substantially governed by the optical properties of the unaltered fiber and radius of curvature. The radius of  
30 curvature may be of the order of or exceed 1000 times the core radius of the unaltered fiber. After thermal annealing the bend angle and radius of curvature are substantially fixed. This embodiment is not an air clad miniature bend but finds application in conventional  
35 connectors and other locations where fiber routing is

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troublesome. After annealing the bare, annealed section of fiber is preferably recoated with a suitable polymer for protective purposes. In this form the bent fiber is large enough to be easily handled during assembly

5 processes.

In various embodiments the bend angle is about 90° or about 180°.

For miniature embodiments, the radius of curvature of the bend is less than 1000 times the radius of the  
10 core of the unaltered main length of the fiber. The selected region is bent tightly around a small diameter support and in certain embodiments the selected region is wrapped a multiplicity of turns around the small diameter support.

15 Preferred embodiments in which the fiber is bent comprise important specific devices. One of these is an optic connector device. Preferably in such a device the fiber optic path extends from a fiber butt end forming a connection interface having a first axis of orientation  
20 through the bend to a fiber portion having an axis lying at a substantial angle to the first axis.

Another important use of the miniature bend aspect of the invention is to realize an improved joint assembly in which regions of the fiber adjacent the selected  
25 region are secured in respective members of a joint which are movable with respect to each other to a limited extent with corresponding bending of the selected region.

Another important use of the invention is to realize improved optic couplers. In one case where the  
30 optic coupler device is formed of a plurality of optic fibers, an extension of one of the fibers forms a fiber optic path having a sharp bend, e.g. 90° and in important instances 180° realized according to the invention. In another case an electro-optic device incorporates the

fiber optic coupler incorporating a miniature bend. A package comprising first and second optical components mounted on a rigid support and connected by the fiber optic path having a miniature bend, in some cases the  
5 first optical component being an optic coupler and the second component selected from the group consisting of light emitters and light detectors; in other cases the package comprises a transceiver comprising a coupler, a light emitter and a light detector.

10 According to another aspect of the invention, a method is provided for reducing the allowable bending radius of an optical fiber, comprising reducing the cross-sectional area of a region of the fiber sufficiently to reduce the optical power loss and  
15 mechanical stresses associated with bending in the region of reduced cross-sectional area, in important instances this reduction being sufficient to achieve an "air clad" state as described above.

There are a number of methods by which a fiber can  
20 be processed to reduce the diameter in a short region for use according to the invention. We describe redrawing the fiber in connection with the preferred embodiments. This simple procedure requires that the unjacketed optical fiber be heated along a length of a few  
25 millimeters until the fiber material reaches a suitable working temperature. The fiber is then drawn so as to elongate the heated region resulting in a gradual taper between the original fiber and the region of reduced cross-sectional area. When done properly the reduced  
30 region has nominally uniform cross-section throughout the effective length of reduction.

Alternatively, fibers may be etched using, e.g., a solution of hydrofluoric acid. Etching, as discussed herein includes all forms of molecular processing.  
35 Therefore, plasma etching, ion milling, solvent

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processing, and any other means relying on the chemical properties of the fiber are considered to be means of etching. Fibers may also be reshaped by mechanical means such as by grinding or polishing. In practice a  
5 combination of means often is best to achieve a particular desired final diameter or an intermediate diameter or shape suitable for secondary processing to the final reduced cross-sectional shape.

Fibers of greatly reduced diameter and relatively  
10 short length, e.g., 2 cm, can be twisted through many complete rotations before breaking. This provides the means to achieve a miniature rotational joint component featuring a continuous length of fiber between units interconnected. Such a joint of the invention  
15 incorporates a single fiber fixed at both ends of a mechanical means comprising two axially aligned pieces which are free to rotate relative to one another about the axis. The fiber section between the fixed points, i.e., that section of fiber subject to twisting when the  
20 mechanical means are rotated, is of greatly reduced diameter. Fibers exiting from the rotational section are of original diameter and can be spliced into other fiber optics with very low loss. The entire assembly can be made very small, of the order of a few centimeters in  
25 length and about a centimeter in diameter, and produces no modulation of optical power in the fiber when rotated. There is, of course, a finite limit to the number of full twists allowed, but for many industrial machine operations, oscillatory rotations of plus or minus 45  
30 angular degrees to plus or minus 360 angular degrees are common. The invention easily meets such requirements for a rotary joint. Similarly, hinge joints, linear translation joints, universal joints, and vibration isolators can be fashioned using the fiber optic methods  
35 of the invention.

Reference is made to the following description of preferred embodiments and the claims for further description of novel features of the invention.

Brief Description of the Figures

5           Fig. 1 shows an optical fiber in successive steps of cross-sectional area reduction including: a) a side view of fiber with jacket removed; b) a side view of fiber after diameter reduction; c) a side view of bent reduced fiber, and d) sections of the fiber area in the  
10 original and reduced regions.

Fig. 2 is a top view schematically illustrating a differential speed uni-directional drawing method: a) before drawing, and b) after drawing.

15           Fig. 3 is a three-dimensional view of a mounting means that fixes the angle of the miniaturized bend.

Fig. 4a is a sectional side view illustrating the main elements of a conventional connector.

20           Fig. 4b is a sectional side view illustrating the main elements of a right-angle connector featuring a miniature bend.

Fig. 4c is a sectional side view illustrating the main elements of a right-angle connector featuring an annealed bend.

25           Fig. 5 is a schematic illustration of the major elements comprising a means to fabricate annealed bends in optical fibers.

Fig. 6 is a three-dimensional view of a reduced fiber fixed in a 180 angular degree bend.

30           Fig. 7 is a sectional side view of a free standing helical coil of reduced fiber in a linear slip joint application.

Fig. 8 is a sectional side view of a length of reduced fiber mounted in a mechanical means suitable to serve as a rotational joint.

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Fig. 9 is a top view of: a) a fiberoptic transceiver using a conventional coupler and full sized fibers, and; b) a transceiver featuring a coupler using the invention to avoid large radius fiber bends inside the transceiver package.

#### Description of Preferred Embodiments

Fig. 1 illustrates the fundamental concept of the miniature bend aspect of the invention. An optical fiber 14 is usually enclosed in a jacketing material 10. The optical fiber 14 is exposed by cutting away a portion of the jacket as between 12 and 12a in Fig. 1a. By means to be discussed herein, the optical fiber 14 is processed so that a selected region of reduced cross-sectional area 18 results. The term cross-section here applies to sections A-A and B-B of Fig. 1c viewed into the axial direction of the fiber. The section A-A represents the original fiber and B-B the reduced fiber as further illustrated in Fig. 1d. In the region of reduced cross-sectional area 18, a bend 20 as illustrated in Fig. 1c can be much smaller than a bend in the original fiber.

The methods of reducing the cross-sectional area of a fiber include etching, machining, and drawing. Combinations of these techniques can also be used. While the nature of the invention is independent of the process used to achieve the reduction, a preferred approach is discussed here.

Drawing a fiber to reduce the cross-sectional area typically has involved heating a region of the fiber to a suitable working temperature and pulling on one or both ends of the fiber so as to elongate the heated region. Experience has shown that single mode fibers can be drawn from an original overall diameter of 130 microns to diameter of less than 0.1 micron with less than 1 percent excess loss of optical power throughout by such well known drawing means. Of particular importance to the

invention is a method we refer to as "differential speed uni-directional drawing".

Differential speed uni-directional drawing describes the novel and extremely useful technique of moving both ends of the heated optical fiber in the same direction at different speeds thus creating a drawing tension in the fiber and hence elongation of the heated region. This is illustrated schematically in Fig. 4. The resulting reduced cross-sectional area remains constant over any desired length of processed fiber. Phenomenologically, the region of constant cross-sectional area 18 results because a steady state is reached wherein fiber material is fed into and extracted from the heated region 26 in Fig. 4 at the same rate. The cross-sectional area required for steady state material flow depends on the difference in speed between the left and right stage, 23 and 25 respectively, when both stages move in the same direction. Therefore, by calibrating the speeds of the stages, long sections of fiber with the same cross-sectional area and shape are produced, and the reduced area can be preselected by choosing a prescribed speed difference.

According to the invention, uni-directional differential speed drawing uses a very small localized heat source such as a microtorch or focused laser beam, operates at relatively small speed differences, and is used to reshape a relatively short length of existing fiber for the advantageous purposes of the invention.

A fiber with cross-sectional area of less than a few square microns requires some form of protective packaging. It is not the purpose of this disclosure to develop all such protective designs, but rather to indicate the scope of some presently embodied as well as foreseen applications of the invention.

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Bends can be embodied in manners to fix one or more of the radii of curvature, the length of curvature, and the bend angle. For example. Fig. 3 illustrates a jacketed optical fiber 32 mounted in a right-angle grooved supporting structure 34. The jacket 10 is shown removed from the section of fiber entering the supporting structure as might result from the processing steps outlined in the discussion of Fig. 1. Here the reduced fiber 18 is bent around 90 angular degrees. It can be seen that the radius of curvature possible in this structure is very small. Typically the fiber can be reduced sufficiently that the mean or minimum radius of curvature is less than the diameter (or smallest overall cross-sectional dimension) of the original fiber. The entire structure of Fig. 3, according to the first aspect of the invention, therefore measures less than 3 millimeters on each side. Without the advantages of the invention the structure would have to measure over 2 centimeters on each side to avoid both excessive optical power loss and the risk of unpredictable breakage.

The bend embodiment depicted generally in Fig. 3 can be used as a miniature right angle routing component. If one thinks of the fiber as entering the structure at the point labeled 36 and exiting the structure at 38, the endface 40 of the exiting fiber might be polished to promote coupling to a photo diode, light emitting diode (LED), laser diode (LD), or for butt coupling to another optical fiber. Any of these devices can be fixed with appropriate bonding methods directly to the endface of the fiber to align with the core 39. In embodiments of those types, the structure shown becomes a right angle pigtail device. Unlike any bending method previously known, this structure is small enough to fit within conventional photodiode, LED, and LD packages. In principle the photodiode can even be deposited directly

on the polished end of the integral fiber/support structure.

Alternatively the fiber could be polished at both end 36 and 38. Such an embodiment can be used as a surface mounted optical bend for routing optical power between elements in miniature electro-optic or integrated optic assemblies. Angles other than 90 degrees and supporting structures more robust than that illustrated conceptually in Fig. 3 are envisioned within the scope of the invention.

Similarly, the concept of Fig. 3 can be extended to include convenient means of routing fibers around bends external to equipment packages. The fiber leaving at point 38 may continue beyond the edge of the bend supporting structure. In such embodiment the structure is a miniature right angle bend useful in packaging fiber runs inside or external to fiber optic equipment.

Figs. 4a and 4b illustrate the advantages of using a miniature bend of the invention in a connector assembly. In Fig. 4a is shown a typical mated pair of fiber optic connectors. Fibers 2 and 6 are held in alignment using ferrules 1 and 5 which closely interfit with the alignment piece 8 which may be bulkhead mounted. Of interest to the invention, the fibers exit the mechanical connector assembly in substantially straight lines through a supporting member 4.

In Fig. 4b a right-angle connector is shown wherein the mechanical supporting means is comprised of an inner guide 9, and outer housing 9a, and a flexible stress relief 19. The miniature bend 11 is formed by means discussed and assembled into the connector with one fiber end fixed by the alignment ferrule 1 and the other end fixed, e.g. by epoxy 15 at the attachment end 17 of the inner housing 9.

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The main section of the optical fiber typically exits from such a connector or connector adaptor assembly in a fiber optic cable 19a. The cable may contain strength members and protective layers not shown in Fig. 4b. It is understood by those skilled in the art that such mechanical cabling requires some form of mechanical termination at the connector output 17. The simplest form of termination, i.e., adhesive 15 fixing is illustrated. Adhesive may also be applied along the internal surfaces of the flexible stress relief 19 thus attaching the cable outer covering 19a to the stress relief 19.

Fig. 4c illustrates an alternative right-angle connector featuring the second aspect of the invention, the annealed bend. The bent region of optical fiber 2a in Fig. 4c has radius of curvature, denoted by the arrow labelled R, typically in the one to two centimeter range depending on the properties of the optical fiber employed. This is not a miniature bend. The bent region is formed by an annealing process to be discussed herein. The connector end of the fiber 2 is mounted in a ferrule 1 as in a conventional connector. A portion 2c of the fiber is fixed in the connector body 3a using, e.g., adhesive 2b. A rigid bent tube 5a acts to protect the bent region of fiber 2a and to locate emerging fiber 2c at some angle, e.g., 90 degrees, relative to the connected fiber 2 axis. The bent tube 5a may be metal or injection molded polymer. The fiber emerges from the tube through a mechanical stress relief 5b which is typically attached to the emerging fiber at the exit orifice 5c using adhesive means.

Alternatively, if a cabled fiber is used in this embodiment, the bent tube and stress relief shall possess cable termination features as discussed in Fig. 4b.

Fig. 5 schematically illustrates a means of manufacturing an annealed bent fiber. The jacketing

material is removed and the fiber is cleaned prior to annealing by methods familiar to those skilled in the art. The fiber 10 is then held in a fixture not shown using clamps 42 so as to form a bent region 43. Heat is  
5 applied to the bent region for a short period of time, the temperature and duration of heating depending upon the type of optical material comprising the fiber. When the heat is removed, the optical material freezes into the shape formed by the clamping means. The annealed  
10 bend is stress free and therefore free from long-term stress induced failure mechanism.

As another example, fiber optic cables leading to desktop equipment can be routed over the edge of the desk using a protective assembly comprised of a supporting  
15 structure to contain a miniature bend and suitable outer packaging to allow easy and esthetically pleasing integration into the office environment. The bend supporting structure might be made flexible to accommodate a broader range of potential needs.

20 Shown in Fig. 6 is a fixed 180 degree bend embodiment. Here a fiber 14 is held by e.g., adhesive 50 in a sleeve 52. This embodiment might be placed anywhere within a continuous length of fiber although here the fiber ends 56 and 58 are shown truncated for graphic  
25 convenience. The radius of curvature of the 180 degree bend 54 is essentially determined by the radius of the original fiber. The structure provides a miniature means to loop a fiber back in the direction from which it came without requiring mirrors and alignment means. This can  
30 prove very useful in integrated optic applications where 180 degrees bend within, e.g. a Lithium Niobate waveguide, cannot be made so small.

The invention, embodied as a helical coil of reduced fiber incorporated into mechanical means to form  
35 a linear slip joint is illustrated in Fig. 7. A jacketed

optical fiber 10, processed as previously described, is reduced in cross-sectional area and wound into a helical coil 60. The free standing fiber coil 60 can be stress relieved by annealing methods known to those skilled in the art if desired. The coil 60, of diameter of a few millimeters, is subsequently mounted with each end fixed by adhesive 62 and 63 in separate mechanical means 64, and 65 which are free to slide, one upon the other. Means 64 and 65 are assembled so that the distance one might slide relative to the other is limited. When means 64 slides upon mean 65, the coil of fiber 60 is either extended or compressed in a spring-like fashion. In Fig. 7 the coil is shown fully compressed. By virtue of the reduced cross-sectional area, a short length of coiled fiber of the order of 5 cm can be made to withstand linear displacements of more than 3 cm.

Fig. 8 illustrates the basic elements of a typical fiber optical rotational connection embodiment of the invention. An optical fiber 10 is reduced in cross-sectional area forming a length of about 1 inch of reduced fiber 68. One end 70 of the fiber is fixed in one separate part 72 of the rotational connection using e.g. adhesive. The other separate part of the connection 74 is mated e.g., by threading the end piece 76 into the body 74 to form the mechanical structure of the connection as depicted here. The other end 78 of the fiber is fixed to the end piece 76 of the connection using e.g., adhesive. The separate parts of the connection are free to rotate about the common longitudinal axis and the reduced fiber 68 lies more or less on that axis. The ends of the connection might be threaded as shown 80 and fixed to separate mechanical structures 84, 86 using nuts 82. A pair of bushings or thrust bearings 87 can be used to reduce slack between the mated rotating mechanical surfaces.

When the separate parts 72 and 74 of the connection are rotated, torsion is applied to the fiber. Such a connection using about 1 inch of fiber reduced to 1 micron diameter can be rotated through more than 360  
5 angular degrees without breakage or loss of optical power, but clearly there is a limit to the number of turns of rotation possible.

Another embodiment of the invention relates to the miniaturization of electro-optic units. As illustrated  
10 schematically in Fig. 9a, a typical fiber optic transceiver uses a bidirectional single fiber link in and out 90. A source of optical power 92 may be connected to one leg 93 of a fiber optic coupler generally indicated by the numeral 94a. A photodetector 95 is connected to  
15 another leg 96 of the coupler 94a on the same side of the coupler as the optical source 92. Light transmitted by the source 92 travels into the coupler 94a, through the optical coupling region and out of the link fiber 90.

The same circuit function is achieved in much less  
20 space by using a fiber optic coupler 94b fashioned to include a miniature bend 106 within the coupler package.

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Claims

1           1. A routing device for changing the direction of  
2 a fiberoptic path from a first axis to a second axis,  
3 said routing device comprising  
4           a short length of low-loss optical fiber having  
5 first and second directed fiber portions aligned  
6 respectively with said first and second axes and a mid-  
7 fiber portion integral with and extending through an arc  
8 of radius of the order of two centimeters or less between  
9 said first and second directed fiber portions;  
10           said mid-portion of fiber being in a treated state  
11 that reduces likelihood of mechanical failure over time  
12 without introducing substantial optical loss;  
13           and an outer member fixing said first and second  
14 directed fiber portions relative to one another in said  
15 angular relationship, said outer member serving to  
16 protect said first and second directed fiber portions and  
17 said mid-portion from the environment.

1           2. The routing device of claim 1 wherein the  
2 radius of said arc is less than 1 centimeter.

1           3. The routing device of claim 1 wherein the mid-  
2 portion of said fiber is disposed in a passage of said  
3 outer member larger in cross section than the cross  
4 section of said mid-portion.

1           4. The routing device of claim 1 or 2 wherein  
2 said mid-fiber portion in the region of its bend has been  
3 treated to have a substantially reduced diameter relative  
4 to the diameter of said directed fiber portions.

1           5. The routing device of claim 4 wherein in said  
2 mid-portion there has been such a reduction in diameter  
3 that the lower index of refraction of the external

4 environment of said fiber at said bend enables  
5 transmission of light energy through said bend with  
6 substantially less bend-loss than would occur if the main  
7 length of said fiber were bent as in said mid-portion.

8           6. The routing device of claim 1, 2, 3 or 4  
9 wherein said fiber in the region of its bend has been  
10 treated to be in a stress-relieved annealed state.

1           7. The routing device of claim 6 wherein said  
2 mid-portion and said directed portions have the same  
3 diameter and said mid-portion is bent to a predetermined  
4 radius of curvature and subsequently heated to a suitable  
5 annealing temperature, said heating being controlled in a  
6 manner to relax mechanical bending stress in the selected  
7 region without increasing the optical power loss  
8 attendant to the predetermined bend and wherein said bend  
9 occurs over an angular range substantially greater than  
10 zero angular degrees and may exceed multiples of 360  
11 angular degrees, said bend having optical power loss  
12 governed by the optical properties of the unaltered fiber  
13 and radius of the unaltered fiber and wherein after  
14 thermal annealing said bend angle and radius of curvature  
15 are substantially fixed.

1           8. The routing device of any of the claims 1-7 in  
2 the form of an angled adaptor, said first and second  
3 directed portions terminating in light-transferring end  
4 faces, said device including connector means for securing  
5 respective additional optical fibers in light-  
6 transferring relationship with said end faces, whereby,  
7 for instance, a patch cord can be made up by connection  
8 of one end of said adaptor to the end of a fiber cable.

1           9. The routing device of any of the claims 1-7  
2 formed as an integral portion of a patch cord or the  
3 like, said optical fiber extending integrally outwardly  
4 from the first said directed portion in a flexible  
5 jacket, said second directed portion terminating in a  
6 light-transferring end face suitable for connection to  
7 another optical fiber in light-transferring relationship.

1           10. The routing device of any of the claims 1-7  
2 formed in the middle of a flexible optical cable, said  
3 optical fiber extending integrally outwardly from each of  
4 said directed portions in a flexible jacket.

1           11. The routing device of any of the claims 1-7  
2 comprised of a fiberoptic ribbon comprised of a plurality  
3 of optical fibers, each of said fibers having directed  
4 portions and an integral mid-portion in the relationship  
5 to each other and to said outer member as defined in  
6 claim 1.

1           12. The routing device of any of the claims 1-7  
2 wherein said predetermined axes are disposed with respect  
3 to each other in a right angle.

1           13. A connection assembly comprising a connection  
2 panel presenting a multiplicity of optical path end faces  
3 for connection to optical fibers, and a corresponding  
4 series of patch cords formed in accordance with claim 8  
5 or 9 the routing devices of said patch cords connected to  
6 said patch board with said end faces thereof in light-  
7 transferring relationship with the optic paths of said  
8 board, the direction change provided by said routing  
9 devices enabling said patch cords to extend in desired  
10 lateral, convenient relationships to said patch board.

1           14. A joint assembly comprising the fiber optic  
2 routing device of any of the claims 1-5 wherein said  
3 directed portions of said fiber are secured in respective  
4 members of a joint which are movable with respect to each  
5 other to a limited extent with corresponding bending of  
6 said selected region.

1           15. A joint assembly comprising the fiber optic  
2 routing device of any of claim 1-6 in the form of a slip  
3 joint wherein said fiber in said mid-portion is bent into  
4 the form of a helical coil such that when said members  
5 move toward each other said helical coil is compressed  
6 and when said members move away from each other said  
7 helical coil is expanded.

1           16. A joint assembly comprising the fiber optic  
2 routing device of any of claims 1-6 in the form of a  
3 rotary joint wherein said directed portions of said fiber  
4 are secured in members of a rotatable joint, said members  
5 being rotatable with respect to each other about an axis  
6 defined by said fiber in said mid-portion, said rotation  
7 twisting said fiber.

1           17. A fiber optic coupler device comprising a  
2 plurality of coupled optical fibers, an extension of one  
3 or more of said coupled fibers forming the fiber optic  
4 path of claim 4.

1           18. A package incorporating a first and second  
2 electro-optic device and at least one fiber optic path of  
3 claim 2 and which further may incorporate one or more  
4 fiber optic devices, said package further may contain  
5 integrated optic components, any and all of which  
6 components may be interconnected in any fashion using one

7 or more of said optical paths, said devices mounted on a  
8 rigid support and connected by said optical paths wherein  
9 said optical components may be fused fiber optic  
10 couplers, the first electro-optic device selected from a  
11 group consisting of light emitters, and the second  
12 electro-optic device selected from a group consisting of  
13 light detectors, and said integrated optic devices  
14 selected from among the groups of optical multiplexers,  
15 optical modulators, optical phase shifters, and optical  
16 polarization controllers.

1 19. A fiber optic path as in claims 1-5 wherein  
2 the optical fiber is single mode.

1 20. A fiber optic path as in claims 1-5 wherein  
2 the optical fiber is multimode.

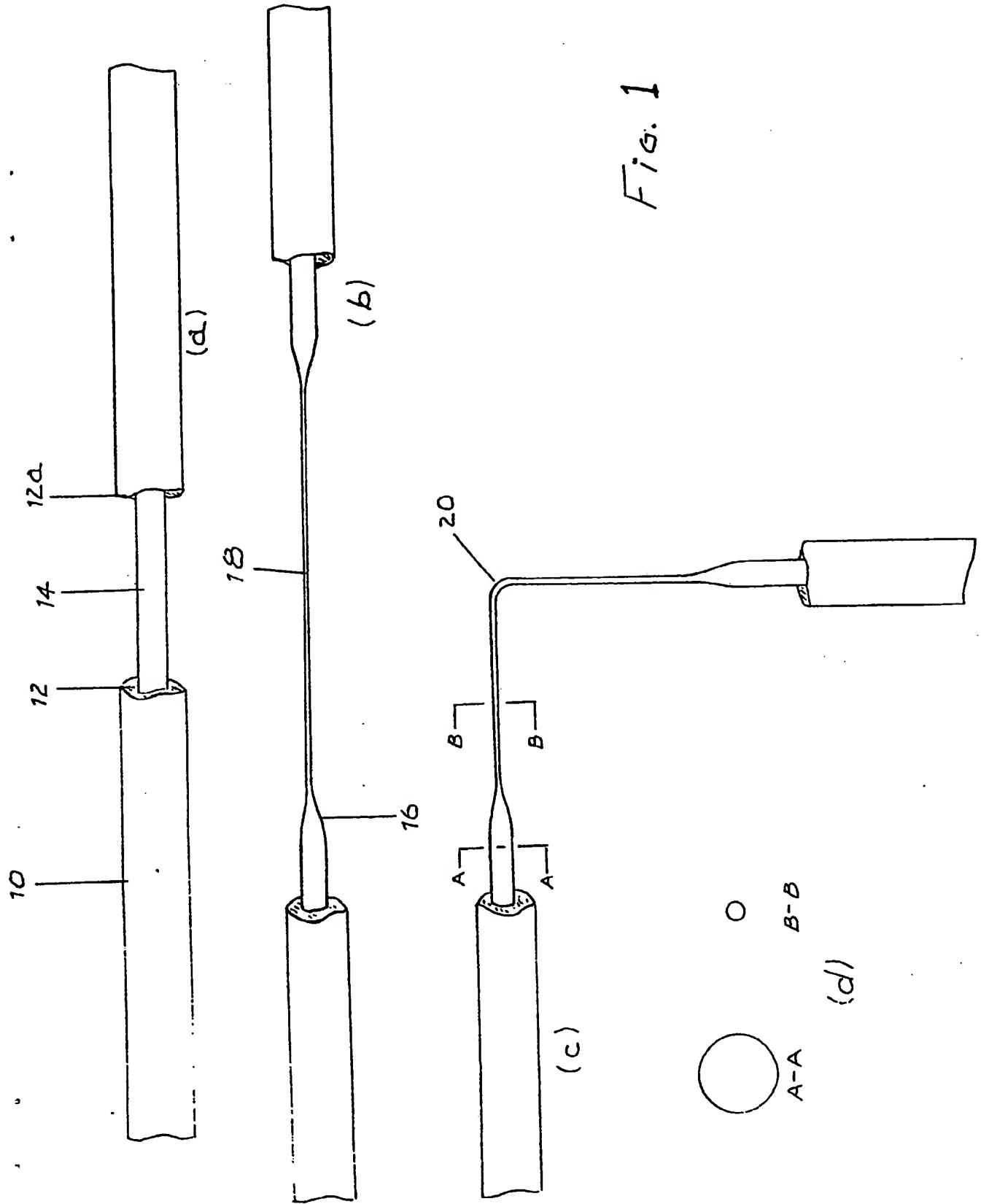
1 21. A fiber optic path as in claims 1-5 wherein  
2 the optical fiber is polarization holding fiber.

1 22. The fiber optic path of claim 3 wherein said  
2 mid-portion results from use of at least one fiber  
3 shaping method including etching, polishing, and drawing,  
4 and may results from any combination of such means.

1 23. A method of drawing a fiber optic path  
2 according to claims 1-4 wherein said mid-portion is  
3 reduced in diameter using differential-speed  
4 unidirectional drawing.

1 24. A method of making a reduced diameter section  
2 of fiber for the purposes of reducing bending loss  
3 wherein the fiber is originally drawn during  
4 manufacturing to include regions of relatively short  
5 length in which the cross-sectional area is reduced, said

- 6 regions of relatively short length being part of the
- 7 continuous length of a standard fiber.



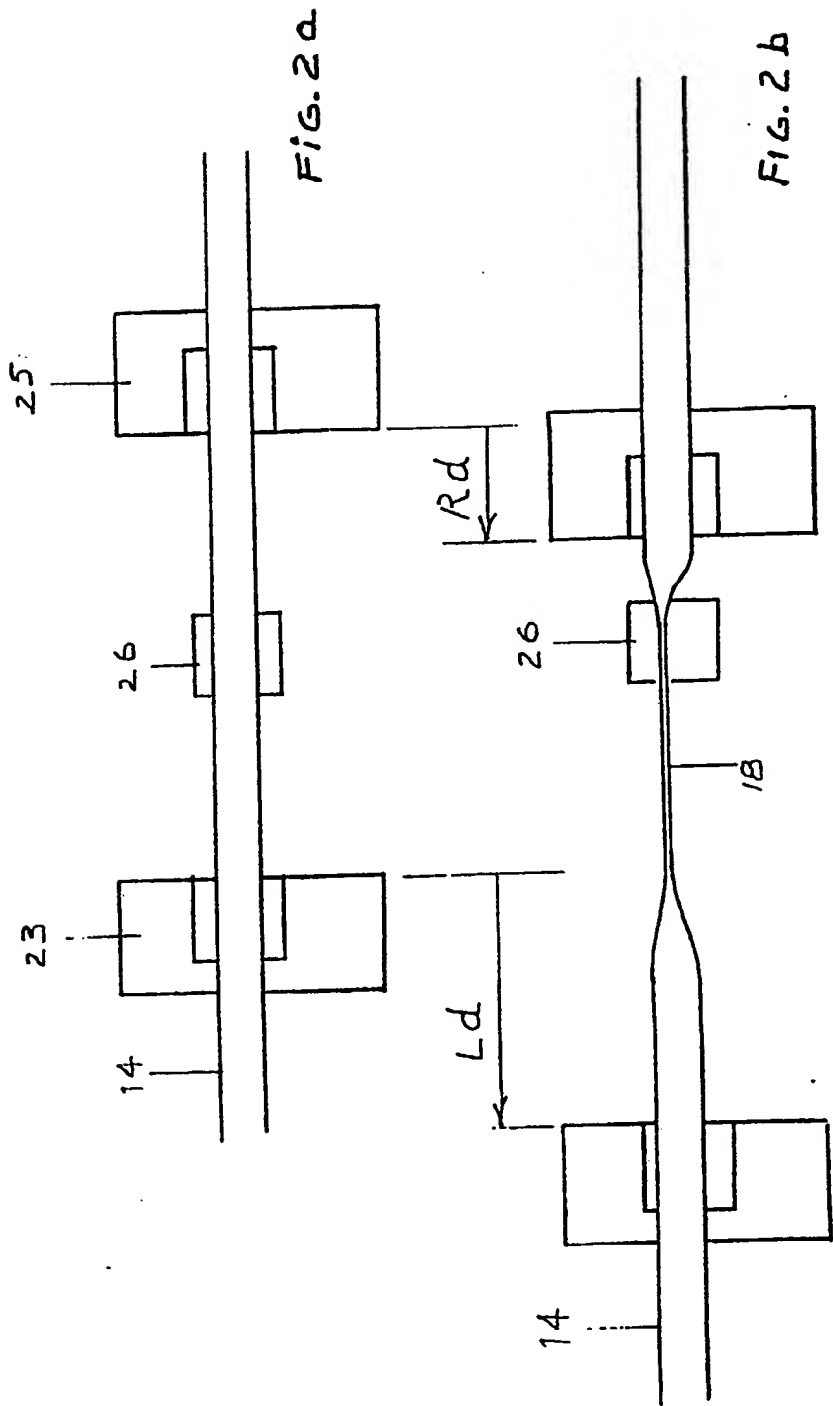


Fig. 2

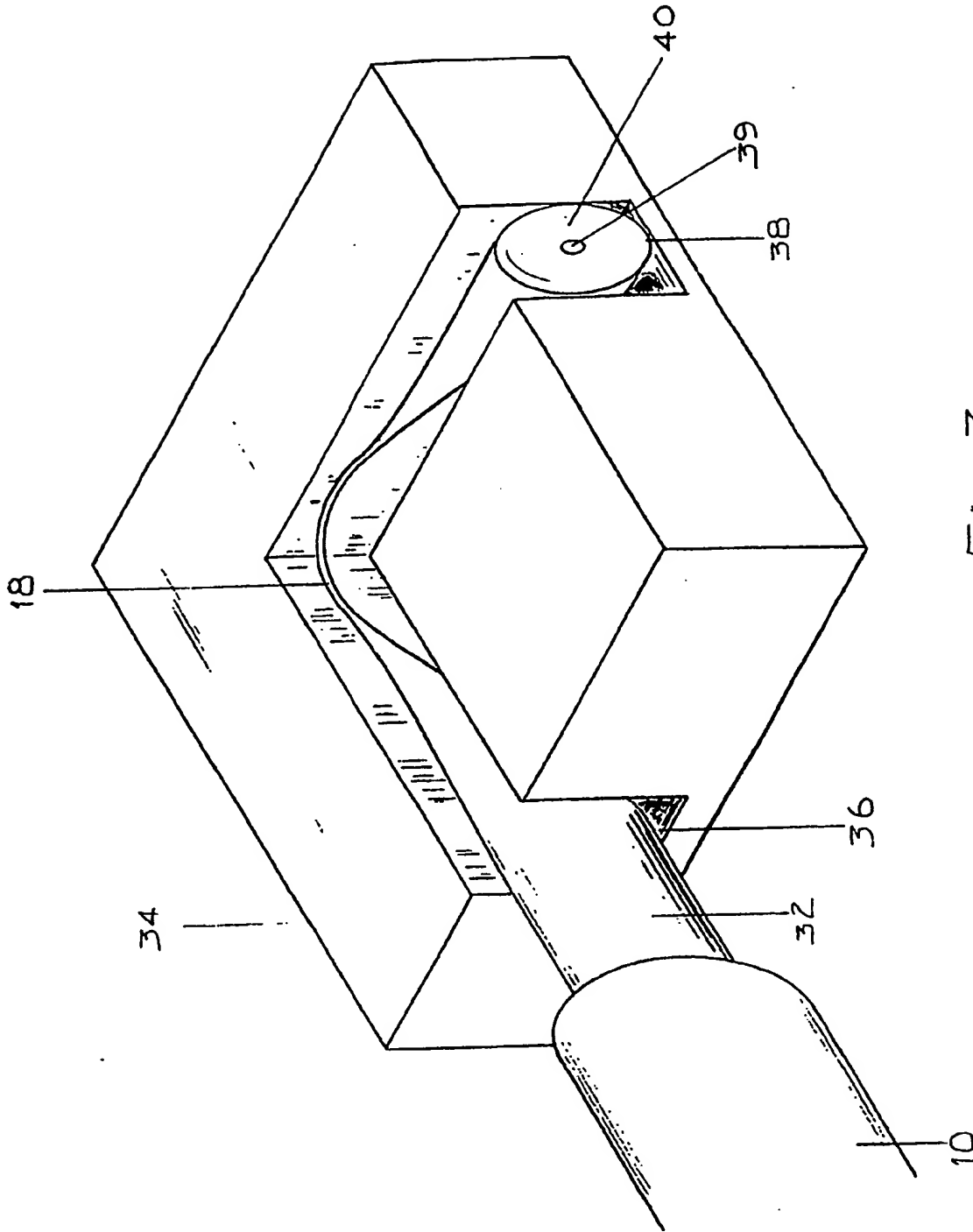


Fig. 3

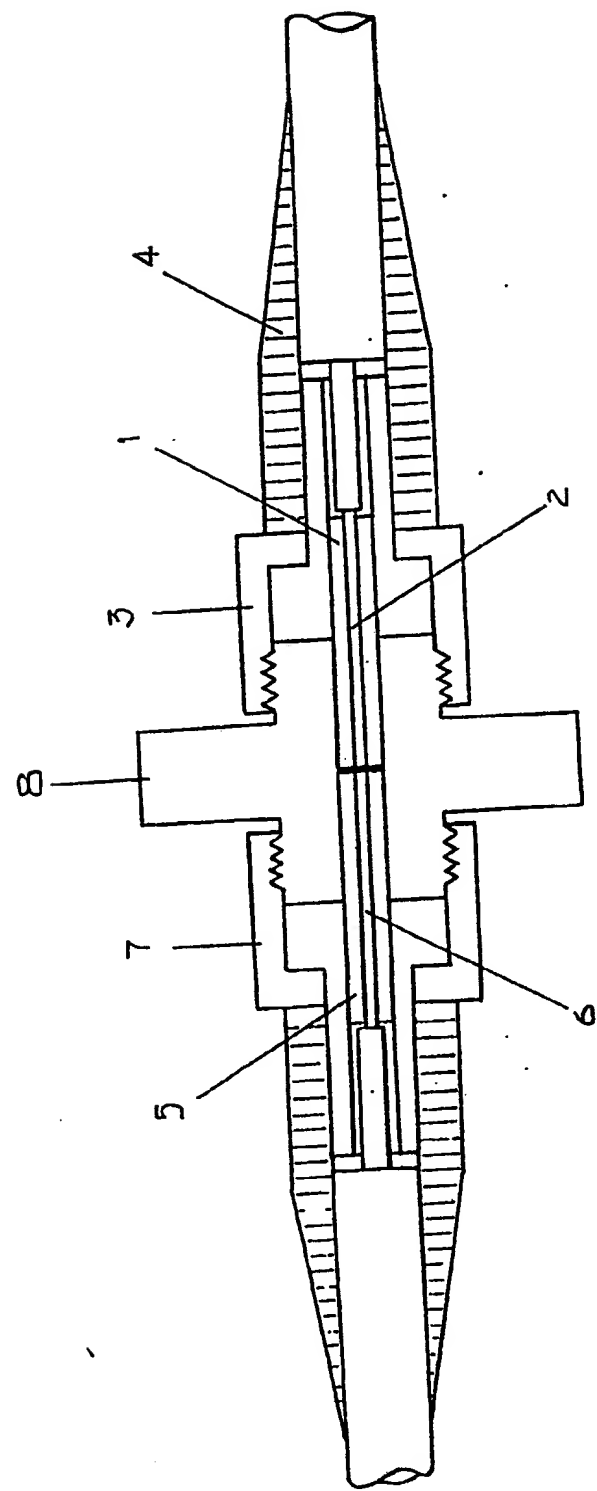


Fig. 4a

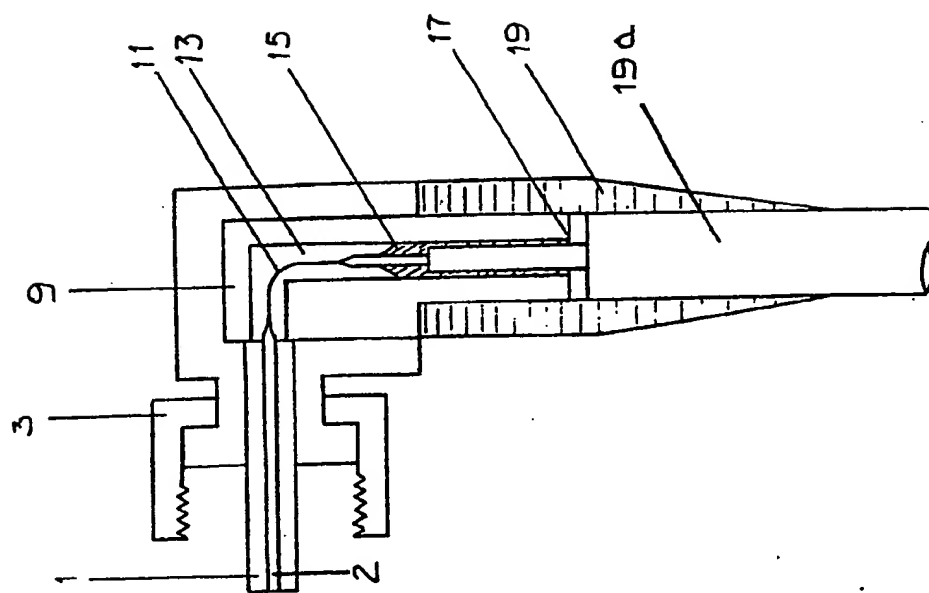


Fig. 4b

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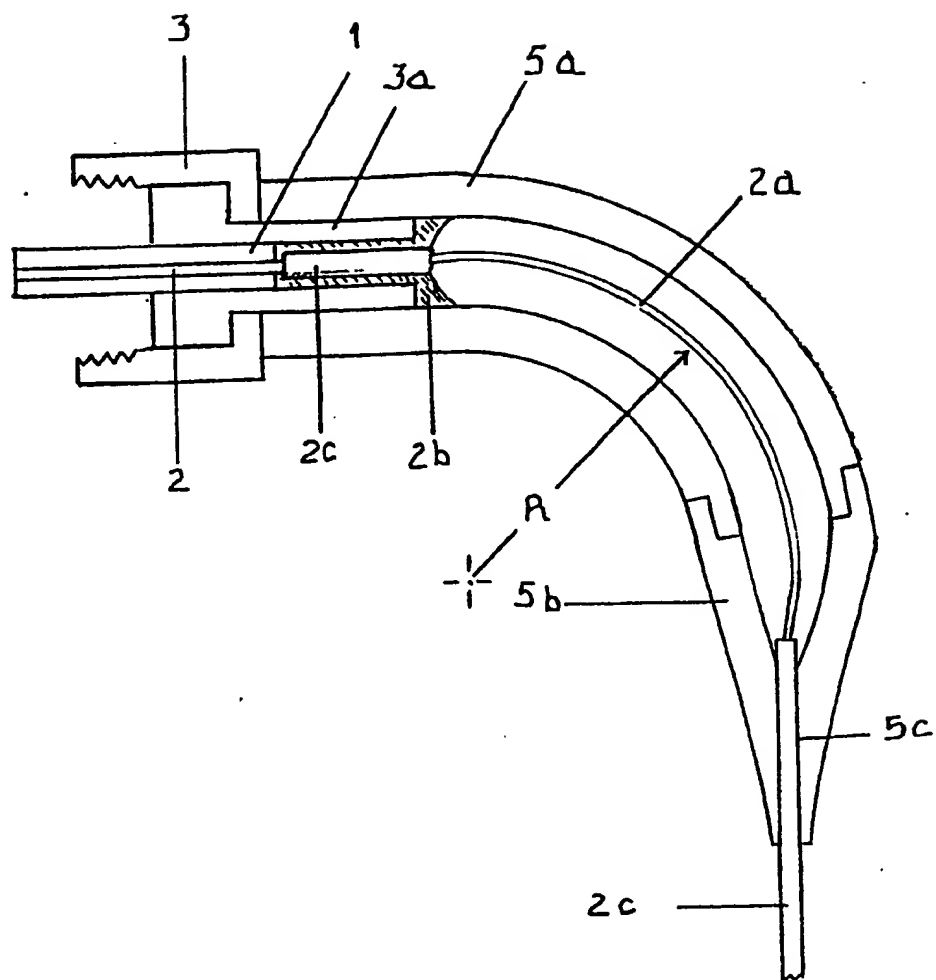


Fig. 4c

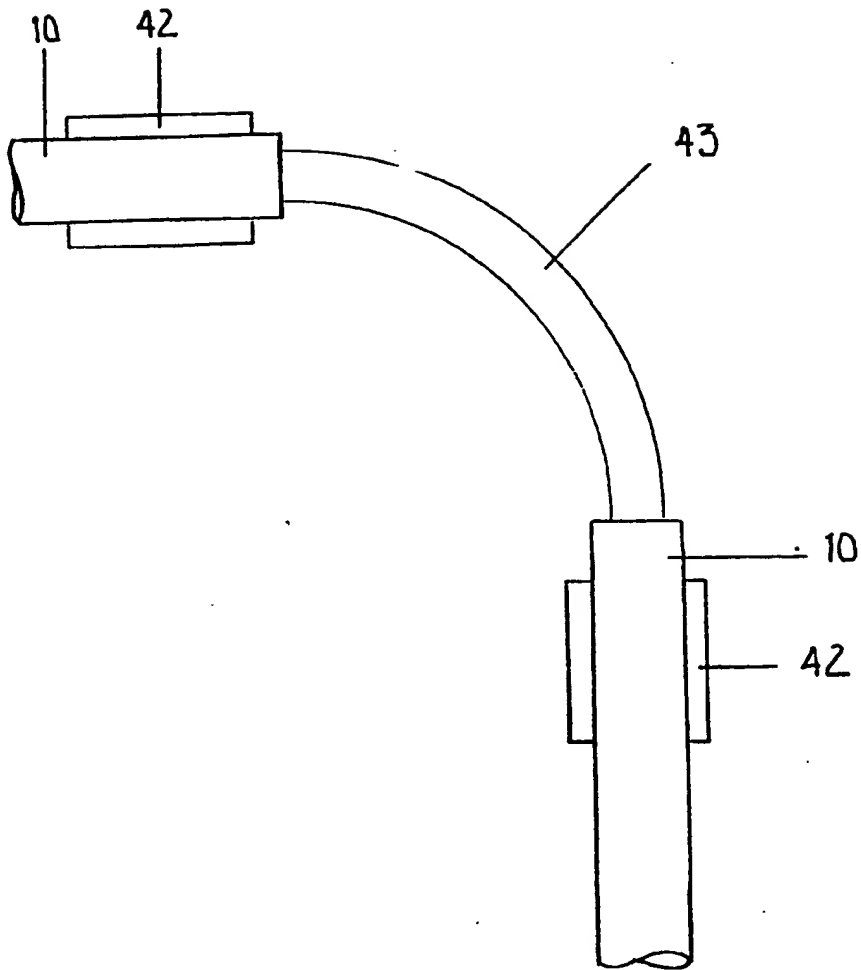


Fig. 5

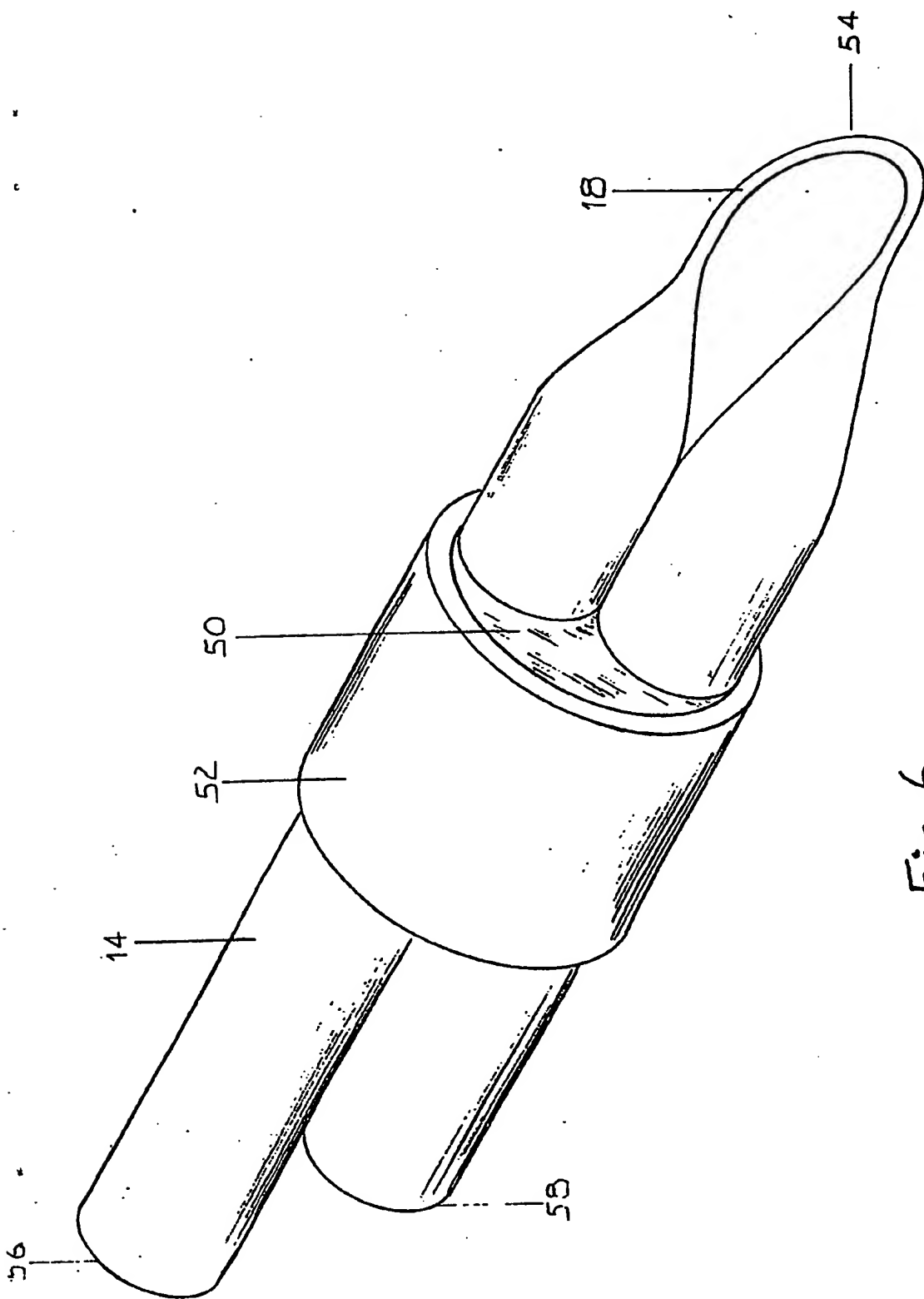


Fig. 6

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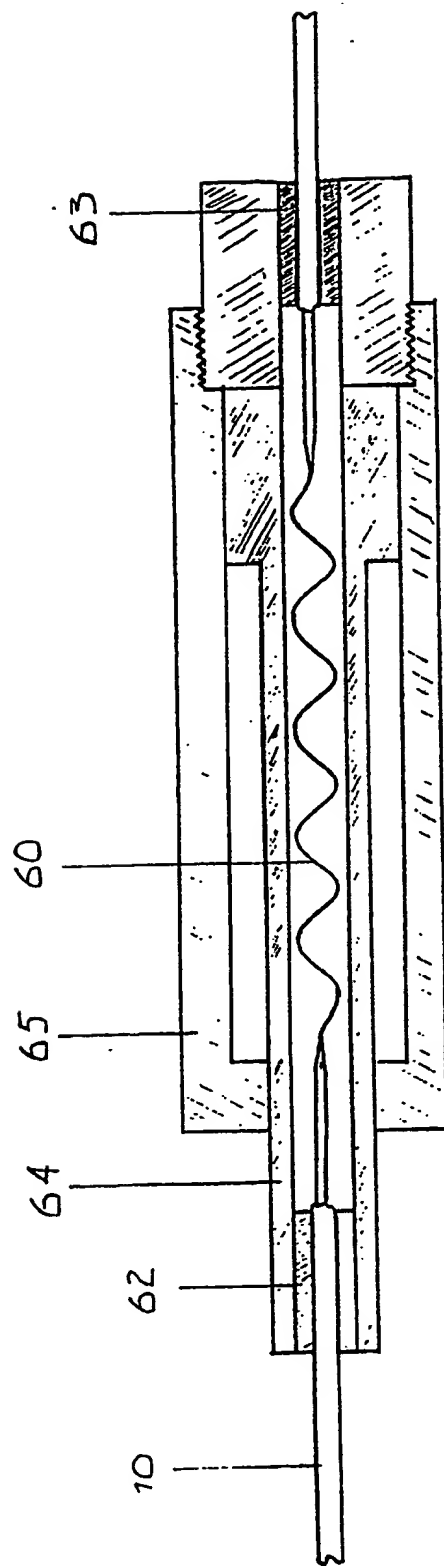


Fig. 7

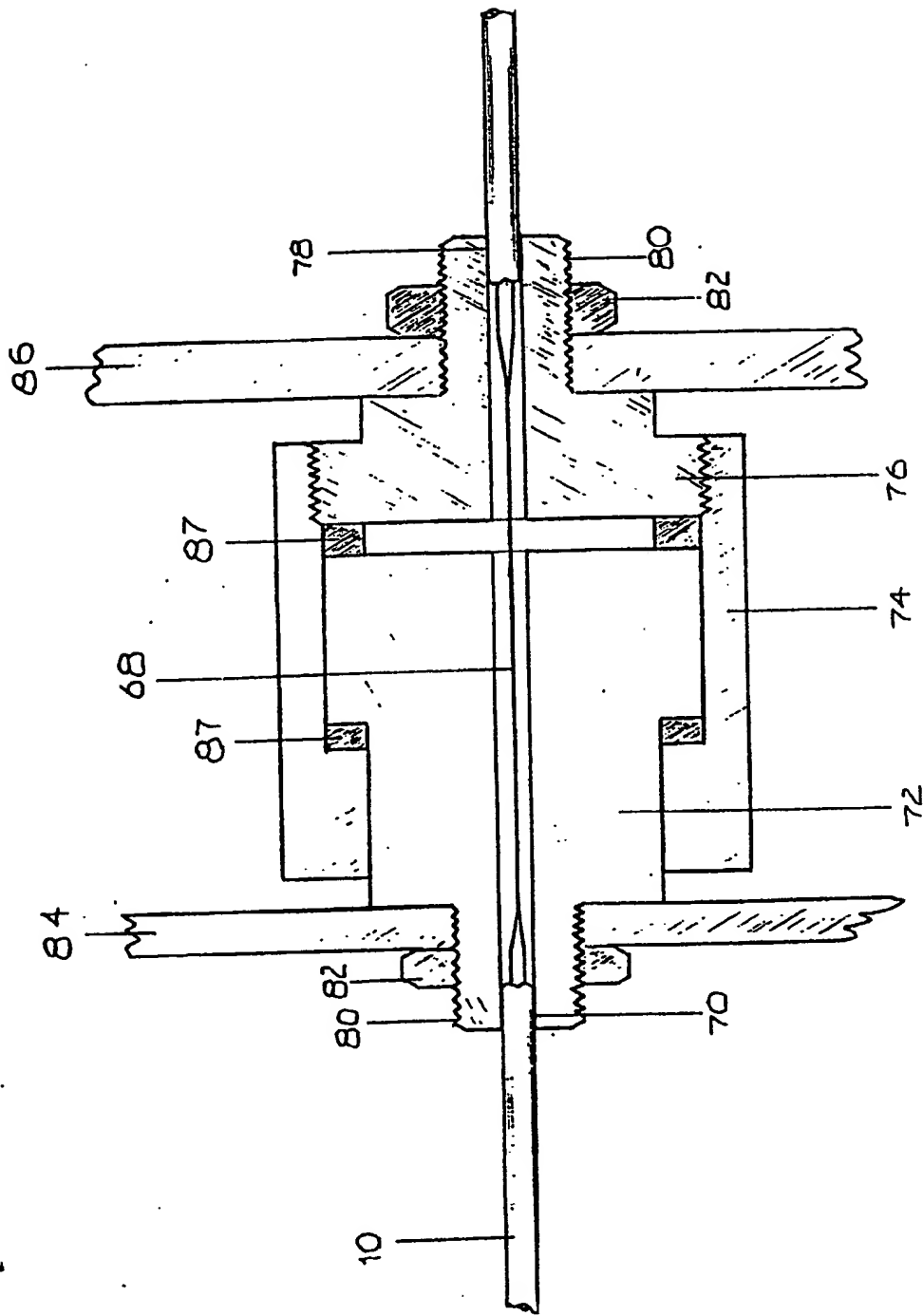


Fig. 8

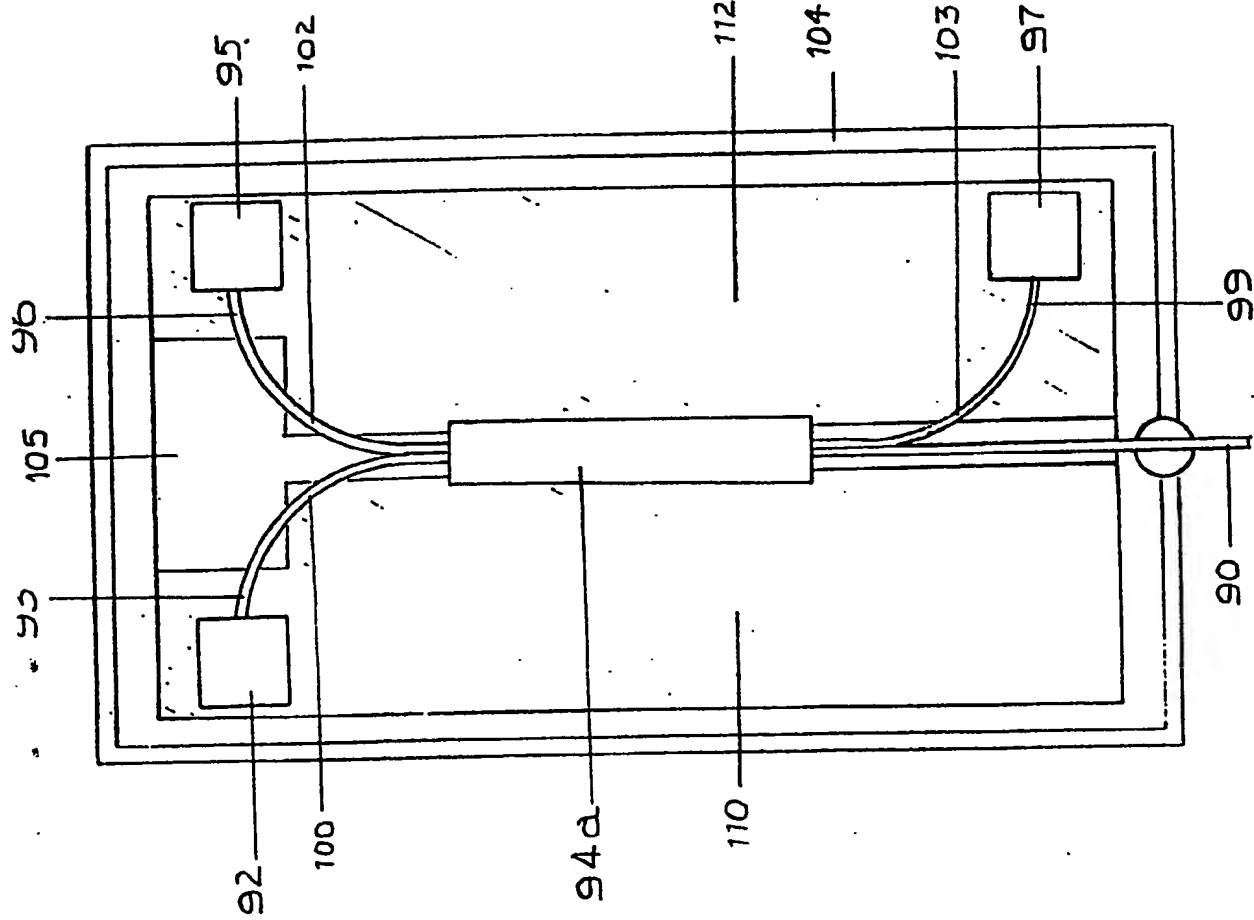


Fig. 9a

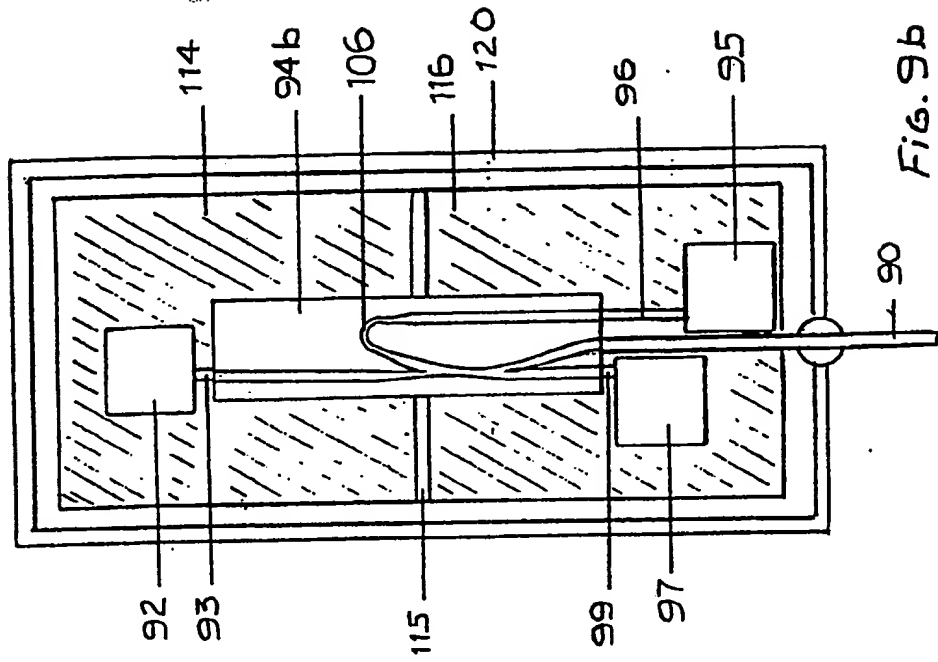


Fig. 9b

Fig. 9

# INTERNATIONAL SEARCH REPORT

International Application No. **PCT/US91/04322**

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (If several classification symbols apply, indicate all) <sup>1</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC		
INT. CL.(5) G02B 6/26		
U.S. CL. 350/96.15		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>4</sup>		
Classification System	Classification Symbols	
U.S.	350/96.15, 96.2, 96.21	
Documentation Searched other than Minimum Documentation to the extent that such Documents are included in the Fields Searched <sup>5</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> <sup>1*</sup>		
Category <sup>*</sup>	Citation of Document, <sup>1*</sup> with indication, where appropriate, of the relevant passages <sup>1*</sup>	Relevant to Claim No. <sup>1*</sup>
A	US, A, 4,906,068 (OLSON et al.) 06 March 1990, (06.03.90) See Figure 3.	1-24
A	SZARKA ET AL., A REVIEW OF BICONICAL TAPER COUPLERS, FIBER AND INTEGRATED OPTICS, VOL. 3, NOS. 2-3, pp. 285-297, SEE Pg. 286 and FIG. 1.	1-24
A P	US, A, 5,011,251 (MILLER ET AL.) 30 April, 1991 (30.04.91) See entire document.	1-24
A	US, A, 4,315,666 (HICKS, JR.) 16 February, 1982 (16.02.82) See entire document.	1-24
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p><sup>*</sup> Special categories of cited documents: <sup>13</sup></p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"Δ" document member of the same patent family</p> </div> </div>		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search <sup>2</sup>		Date of Mailing of this International Search Report <sup>2</sup>
13 August 1991		11 SEP 1991
International Searching Authority <sup>1</sup>		Signature of Authorized Officer <sup>10</sup>
ISA/US		Stephen W. Barnes